2.1 Introduction

The XFD Operations Organization is responsible for assuring that the APS effectively meets the operational needs of the user community and for assuring that XFD and user activities conform to the applicable requirements. In support of the APS user activities, the XFD Operations Organization also gathers specific facility operating requirements, integrates the requests, determines the operating modes that are needed to meet the requirements, and works with the Accelerator Systems Division (ASD) to satisfy the requirements. The Operations Organization is under the direction of an Associate Division Director for Operations and includes three major groups: the Beamline Operations Group, the Interlock Systems and Instrumentation Group, and the Experiment Floor Operations Group, as well as support staff to aid the group activities. The latter group was organized recently and consists of the floor coordinators, who were transferred to Operations from the User Technical Interface Group. The activities of these groups are described in more detail in the following sections.

2.2 Installation and Commissioning Status

The APS storage ring design incorporates a magnetic lattice with 35 5-meter-long straight sections available for installation of insertion devices (IDs). The design also incorporates the necessary beam ports for extracting radiation from 35 of the 80 storage ring bending magnets (BMs). With each sector containing an ID beamline and a BM beamline, the APS can accommodate a total of 70 beamlines. The funding for the APS Project included the funds to construct 20 sectors worth of front ends (FEs) and IDs available for user research and an additional sector for particle beam diagnostics studies by the APS facility. All of these FEs and IDs have been installed, and most have been commissioned and are providing beam to the user beamlines. Two additional sectors have received funding, and work is underway to fabricate the necessary IDs and FE components. Installation of these components is planned to begin in 1999. The remaining 12 IDs and 24 FEs will be built and installed as future funding becomes available.

User beamline installation continues, although the installation schedule is primarily governed by the user funding availability. The APS personnel are responsible for managing the installation contracts of the experiment stations and beamline utilities. As of July 1998, 101 experiment stations have been completed on 31 beamlines. Of these 31 beamlines, all have had x-rays delivered to at least the first optics enclosure (FOE). The dates for the start of commissioning, for each of these beamlines, are shown in Table 2.1. Another seven stations are either under construction or are planned for the near future. The current beamline status is shown in Fig. 2.1.

2.3 Operations Experience

It is now three and one-half years since the storage ring began commissioning on February 20, 1995. The facility has developed and improved substantially over that period. In calendar year 1996, about 2000 hours of time were scheduled for user operations. Last year, this number was

Table 2.1. Dates of First Commissioning of APS Beamlines

Beamline	Date of First Beam
1-BM	3/26/95
1-ID	8/9/95
2-BM	6/24/96
2-ID	3/26/96
3-ID	1/24/96
5-BM	3/27/96
5-ID	5/2296
6-ID	2/3/98
7-BM	11/11/97
7-ID	8/16/96
8-ID	8/17/96
9-BM	3/31/98
9-ID	3/31/98
10-ID	8/8/96
11-ID	1/14/97
12-BM	3/26/96
12-ID	5/20/96
13-BM	9/17/96
13-ID	9/27/96
14-BM	4/21/97
14-ID	4/22/97
15-ID	6/16/98
17-BM	10/14/96
17-ID	7/5/96
18-ID	6/12/97
19-BM	625/96
19-ID	3/26/96
20-BM	5/26/98
20-ID	12/18/96
33-BM	6/30/98
33-ID	7/3/96
35-ID	3/6/97

3500 hours. This year, the facility will provide 4500 hours of user time, and the plan is to provide 5000 hours in 1999. Troublesome systems have been identified and major faults corrected. This has led to a significant increase in the availability of the beam and has also led to a significant decrease in the number of faults that caused the stored beam to be dumped. The improvements have involved significant effort from personnel of both ASD and XFD. Reliability issues relative to XFD components are discussed in the next section. Unplanned beam dumps not only decrease the available beam time due to the subsequent refill but also cause additional loss of time as optics and other experimental equipment recover from the thermal cycle. This effect varies from beamline to beamline and cannot be accounted for in the operating statistics. The user run statistics from the start of detailed record keeping in June 1996 to the present are shown in Table 2.2.

Since the facility has little control over the installation of user beamline components, the schedule for user beamline commissioning and operation is governed by each user organization. However, XFD Operations monitors the amount of beam usage by tracking the amount of time that the FE shutters are open. This parameter has increased significantly over the last 18 months and is shown in Fig. 2.2 as the sum of shutter open hours per available hour of user time. This number substantiates the ever-increasing number of experiment safety reviews that are being submitted by the user groups.

The operating schedule continues to be optimized as storage ring, ID, FE and user needs are better defined. As the understanding of storage ring performance increases, the time allocated to accelerator studies has decreased from 30% to 15% of the operating time. Since the current installation work for the FEs has been completed, longer shutdowns are not scheduled as frequently, and user runs are considerably longer, lasting as long as 8-9 weeks. However, to facilitate repairs during long user runs, a total of seven shifts are set

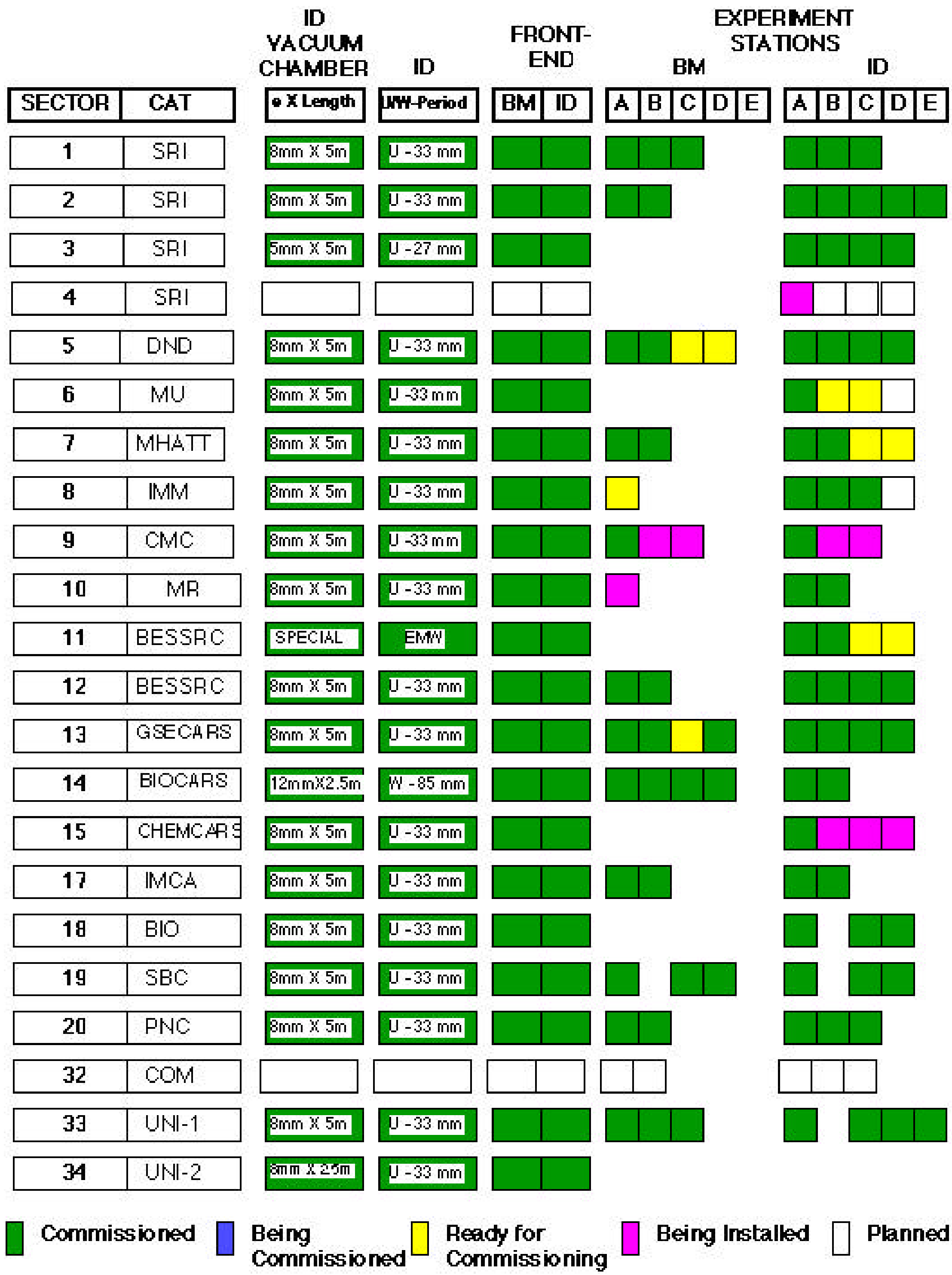

Fig. 2.1 APS CAT Beamline Status as of July 1998.

Table 2.2. User run statistics

User Run	Run start / end dates	Scheduled hours	Available hours	Availability %	Faults per day
96-4	6/22/96 - 7/7/96	300.0	239.8	79.9%	NA
96-5	8/5/96 - 8/19/96	324.0	201.9	62.3%	8.3
96-6	9/17/96 - 10/20/96	596.0	456.0	76.5%	7.4
96-7	12/10/96 - 12/23/96	268.0	183.0	68.3%	3.4
1996		1488.0	1080.7	72.6%	
97-1	1/7/97 - 1/25/97	376.0	264.8	70.4%	5.5
97-2	2/25/97 - 3/9/97	296.0	206.0	69.6%	5.7
97-3	4/8/97 - 5/3/97	480.0	290.0	60.4%	6.8
97-4	5/28/97 - 6/15/97	384.0	327.3	85.2%	1.9
97-5	7/15/97 - 8/3/97	408.0	318.5	78.1%	4.4
97-6	8/19/97 - 9/29/97	864.0	752.9	87.1%	1.4
97-7	10/20/97 - 11/24/97	744.0	699.4	94.0%	0.58
1997		3552.0	2858.9	80.5%	
98-1	1/12/98 - 2/16/98	712.0	655.4	92.0%	0.79
98-2	3/9/98 - 4/12/98	736.0	655.7	89.1%	0.99
98-3	5/18/98 - 7/12/98	1168.0	1100.2	94.2%	0.62
1998		2616.0	2411.2	92.2%	

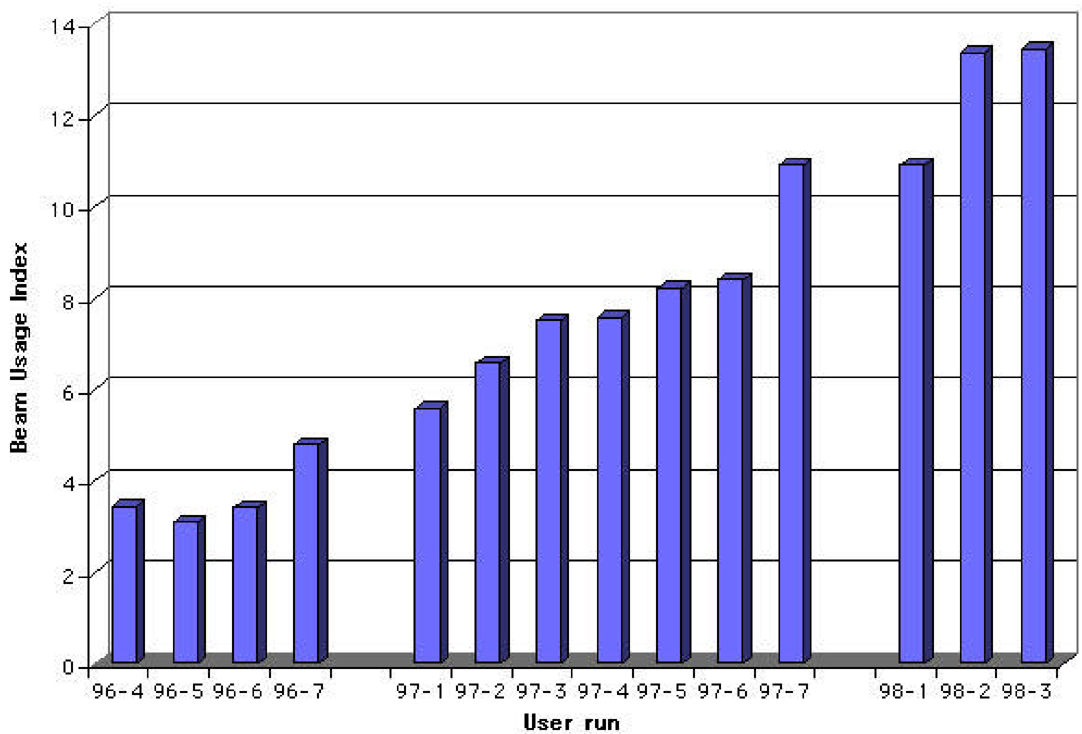

Fig. 2.2 Beamline shutter use plotted as as the sum of shutter open hours per available hours of user time.

aside during each two-week period for maintenance, repair and/or accelerator studies: six continuous shifts every two weeks and a single shift during the intervening week. The available “free” time will decrease even further next year as 5000 hours are provided for users. Since two additional FEs are also scheduled for installation next year, precise scheduling will be required to accomplish the installation tasks within the allotted times without impacting the user runs.

2.4 Reliability Analysis

Statistical data gathering for the Advanced Photon Source beamlines is an on-going effort aimed at monitoring the reliability of the operational systems (IDs and FEs) down to the components level. This effort is targeted at achieving the following goals:

- Increase availability of beam time to the user community
- Minimize failures and prevent their recurrence
- Predict failures before occurrence

Failures or malfunctions of any equipment that is required to directly support or operate the beamlines or that is related to personnel or equipment safety must be reported and tracked to resolution. Failures are diagnosed and followed up by the cognizant individuals and tracked/analyzed by the quality assurance (QA) reliability engineers.

All system/component performance data from the Experimental Physics and Industrial Control System (EPICS) is constantly logged and monitored. This facilitates data gathering and analysis of specific trends and provides the flexibility for advance warning on failures. Problems can then be dealt with in a pro-active manner.

The life history of each critical component is maintained in the Equipment Tracking System (ETS). This is a database system written in ORACLE designed to archive key information on beamline critical components.

The ETS can keep a complete history of each individual component from incoming inspection to failure and/or removal from service. In addition, users can be notified of maintenance and calibration requirements of components when applicable. Hard copy reports are also available of all data to make analysis much easier and more useful.

This database has been adapted for use on the APS Web page. The main benefit of this exercise is to make the data more accessible for users. On the Web, a user/operator is able to obtain a complete FE or ID component list on-screen simply by clicking on the appropriate sector prompt. The user could then click on a specific component in the list, and a pop-up window will appear with more detailed information on the component of interest.

Another benefit of adapting the ETS to the Web is the ability to connect the ETS database fields with current XFD Operations Web sites. XFD Operations is currently employing a failure reporting system called Trouble Reports on the Web. Trouble Reports are generated when any problem arises during normal operations. Data gathered from the trouble reports and the repair logs are analyzed for failure correlations and trends.

In order to pro-actively maintain the beamline components, the ETS also has the capability of generating maintenance schedules for performing preventive maintenance during beam shutdown periods.

To date, 43 FEs and 21 ID systems are in the operational stage. Failure or malfunction data have been collected on these systems by XFD personnel through the construction, installation, and operation phases of the APS FEs and IDs. The data have been organized into two main groups: 1) critical component rejections during incoming inspection, and 2) failures after component installation and operation. Rejections during incoming inspection are documented using the ANL nonconformance reports and are also entered into the XFD ETS database. Component anomalies after installation and operation are logged into the XFD Operations Trouble Reports, which are Web based.

Operational data on the APS beamlines gathered to date have been analyzed. The number of failures documented thus far are shown in Fig 2.3. For the operational analysis, only components that failed and were either removed from service or repaired and reinstalled were included. Figure 2.3 shows both the number of rejections at incoming inspection to date as well as the failures during operations for each quarter starting with the second quarter of 1996. Rejections at incoming inspection

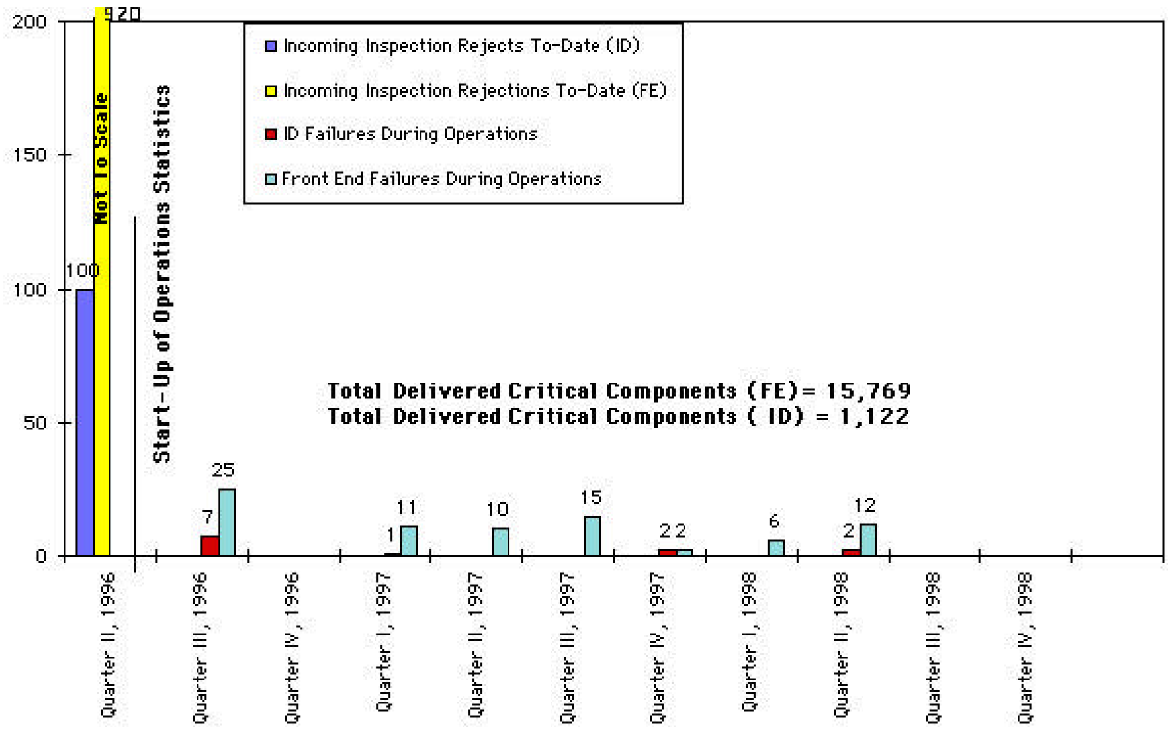

Fig. 2.3 Statistical data on component performance.

do not appear after Quarter II 1996, because the majority of critical components for the FEs and IDs were already inspected at that time. A manufacturing problem with the FE pressure transmitters led to rejection of 380 units accounting for 41% of the total rejections.

Failures after installation and operation fall into three main categories: mechanical, electrical, and vacuum. Electrical and mechanical failures are the most prevalent, occurring in cases such as modules for the PSS and EPS, encoders, controllers, and pressure transmitters. To a lesser extent, vacuum leaks have been recognized on FE equipment as well.

Analysis of the statistical data gathered for the period covered by this report indicates the following:

1. The XFD Operations contribution to x-ray beam downtime during the 12-month operational cycles (from Quarter II 1997 to Quarter II 1998) is depicted in Fig. 2.4. With a total of 5496 hours of user beam time, the XFD operations systems contributed to 37.4 hours of downtime representing 0.68% of the total scheduled user beam time.

2. A graphical representation of the systems contributing to the XFD operational downtime and the distribution is shown in Fig. 2.5. Further breakdown of the root cause for failures and trends occurring in each system indicates the following:

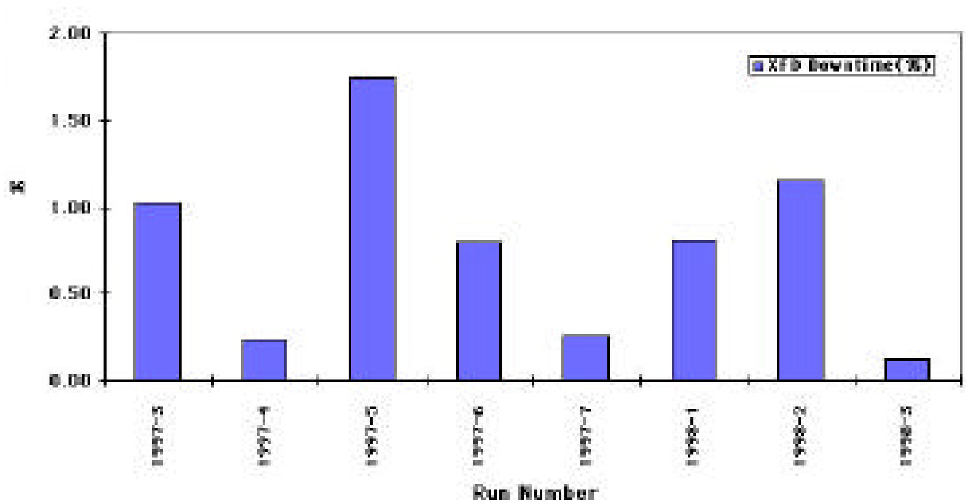

Fig. 2.4 Percentage of XFD downtime compared to scheduled beam running time.

- The PSS system failures can be broken down into two main categories: 1) photon shutters and 2) enclosure doors. Over 80% of the FE shutter failures involved only the second photon shutter (PS2). The one signature symptom of the shutter problem is a slow opening actuator. An ongoing effort is in place to identify the root cause of the problem. Corrective action will be implemented based on these results. Most station-door-related PSS failures were sluggish door operation, usually due to pneumatics problems. A program is now in place to provide semi-annual preventive maintenance to all beamline enclosure doors.

- Half of the ID system failures reported were for motor-related problems, primarily for stalling of IDs prior to upgrading the stepper motor drivers from 8- to 12-amp units. Another quarter of the failures were due to ID control hardware problems. Reset errors from the linear encoders contributed to this. Encoders that exhibited this problem have been readjusted and or modified to prevent recurrence. The remaining problems related to the ID system were for access security/gateway and software problems, which are nonrecurring in both of these areas.

- Almost half of FE system failures reported during the period covered by this report are related to the cooling water system, with transmitter problems being the major cause. Vacuum-related problems were the second source of failure for the FE system, either from actual vacuum leaks or from very high beam-induced outgassing, which

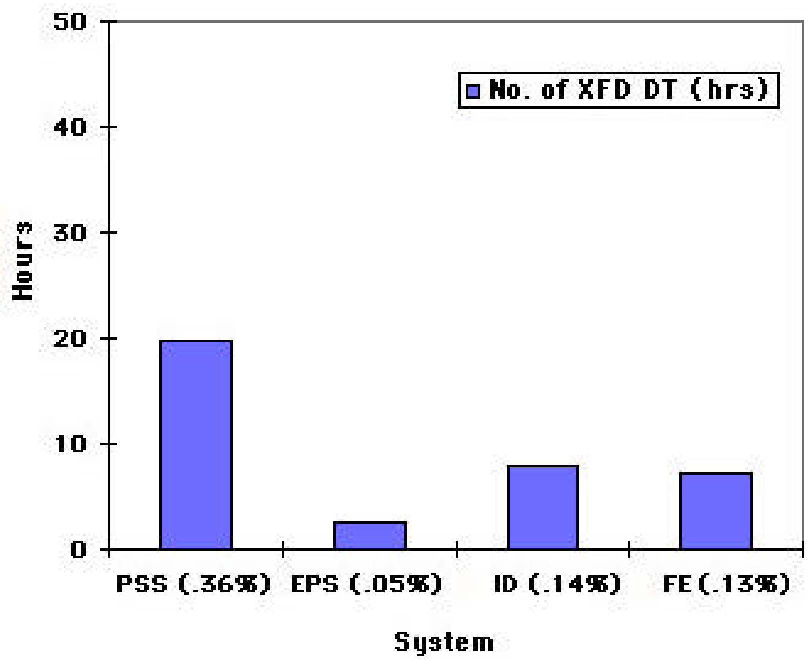

Fig. 2.5 System/component failures impacting beamline operations in delivering 5496 hours of user beam time.

caused high pressure levels that tripped setpoint-actuated interlocks. The most significant failure occurred in March 1998, when a ratchet-wall collimator developed a major leak taking an entire beamline off-line (see sections 2.6.6 and 5.2.2).

- Failures reported for the EPS system are usually due to problems, such as vacuum or water systems, that cause an EPS trip. Since the APS became operational in December of 1996, the FE EPS system has never failed as an operational system.

2.5 Maintenance

The maintenance program of the XFD operational systems consists of three parts:

1) Preventive maintenance includes tasks performed on a scheduled periodic basis to prevent failures while equipment is in use. This is accomplished in part by constantly monitoring equipment performance via the EPICS data logs. Maintenance schedules of this nature are driven mainly by beam run-time schedules due to the fact that much of the work can only be performed during shutdown periods. In addition, as shutdown time decreases, it becomes

critical to optimize the amount of work performed. Undulator maintenance is a prime example of this.

2) Reliability-centered maintenance includes a scheduled maintenance program that increases the availability of an item of equipment by identifying failures or potential failures before they degrade equipment effectiveness. Examples of this type of maintenance are the semi-annual PSS validation and door maintenance program.

3) Emergency maintenance includes accidental failures for which a good inventory of spare parts is maintained.

2.6 Beamline Operations

2.6.1 Introduction

The Beamline Operations Group is responsible for reliable operation of all FEs and IDs. In this effort, the Group regularly uses the expertise of personnel in the Insertion Devices Group and the Beamline Engineering Group in XFD. The Beamline Operations Group is also responsible for providing technical support to users. All the Phase-1 40 FEs and 20 IDs were installed. In addition, the ASD diagnostic beamline, sector 35, was commissioned with a special undulator and a different type of FE. During the past year, of the original 20 IDs installed, 19 provided radiation to the beamlines on the experiment hall floor. Also of the 20 bending magnet beamlines, 12 provided radiation to the beamlines on the experiment hall floor. This past year was mainly devoted to maintenance and upgrades of existing FEs and IDs.

2.6.2 Insertion Devices

Currently, a total of 22 IDs are installed in 21 sectors of the storage ring. Most devices are 3.3-cm-period undulators, 2.4 meters long. Sector 2 has two devices installed, one 3.3-cm-period undulator and one 5.5-cm-period undulator. Sector 3 has a 2.7-cm-period undulator. Sector 11 has an elliptical multipole wiggler (EMW). Sector 14 has an 8.5-cm-period wiggler, and sector 35 has a 1.8-cm-period 4.5-meter-long undulator.

The ID vacuum chamber in sector 3 was replaced with a small vertical aperture chamber with a maximum vertical opening of 5 mm and an external vertical size of 8 mm. This change has enabled the 2.7-cm-period undulator to reach a gap of 8.5 mm, which corresponds to a first harmonic energy of 5 keV, enhancing the capability of the sector 3 beamline.

All ID vacuum chambers have a transition chamber at either end, which allows the conversion from the standard 40-mm-aperture storage ring chamber to the 8-mm ID chamber. Internally, these transition chambers are made of copper and are water cooled as they are exposed to a significant heat load during normal operation due to radio frequency (RF) heating. Recently on some sectors there was a significant pressure drop across these cooling lines. The technique developed to clean FE components was adapted to clean these absorber cooling lines. In addition the cooling circuits were reconfigured to be part of lower flow circuits.

Upgrades to the IDs were undertaken to enhance their capabilities and to increase their reliability. All IDs, with the exception of the EMW in sector 11, were retrofitted with new machine protection system switches and actuators. This arrangement allows the switches to trip at a gap of 50 mm and stay tripped at any gap larger than 50 mm. The upgrade provides confirmation that the gaps are effectively "open" without having to fully open the devices to 200 mm. This capability has effectively reduced the storage ring refill times by nearly 50%. During the past year, many of the devices began stalling at moderate speeds. To overcome this problem, the stepping motor drivers were upgraded from 8-amp to 12-amp capacity. More than half the sectors are currently equipped with the new stepping motor drivers. The higher current drivers allow the existing ID motors to produce more torque, resulting in more reliable ID operation, faster acceleration, and higher opening and closing speeds. This is a major benefit to users who are "scanning" an ID, moving the gap to a new energy, and taking data every few seconds. Linear potentiometers were installed on all devices as a redundant method of gap measurement. They can be used as input for the EPS. They are also used as inputs for a gap monitor system in sectors with multiple IDs, such as sector 2, where two devices are installed and the FE components cannot handle the power of both devices simultaneously at fully closed gaps.

Extensive modifications were made to the ID control software for more reliable operation, user friendliness, and easier revision when new features are added. A beamline commissioning limit was established, allowing users to specify a minimum gap for ID operation for protection of their own beamline and experimental components. This software limit is independent of limits established for protection of the ID, ID vacuum chamber, FE components, and experiment stations. A "deadband" was added to the control program to allow users to specify a tolerance on the desired gap. This is especially useful for scanning of the ID in small steps over a certain energy range. Time is not wasted in extremely precise positioning of the ID if lower precision is acceptable for the experimental demands of the user. The gap-to-energy conversion in the ID control software was enhanced. New code is used to correct the energy calculation to correspond more closely to the x-ray energy. The finite beam size is taken into consideration in calculating the energy for any specific harmonic and gap. Users were given the option of specifying the required harmonic (maximum 7th order) for energy readback and control values.

2.6.3 Front Ends

Currently there are 41 FEs installed, of these, 31 have provided radiation to the experiment hall floor and 20 (including sector 35-ID) are for ID beamlines. During the course of the last few years of operation, certain inherent problems have surfaced. In addition to resolving these problems, upgrades and modifications have been performed.

The EPICS interface to the FE controls was enhanced during the past year. Control of the all the devices is now possible via EPICS. At the present time, floor coordinators and operators can reset faults and open and close vacuum valves remotely from their workstations. Access security was implemented to avoid unwarranted operation of devices. In addition the FE system manager can control all the vacuum pumps. Residual gas analyzers (RGAs) in all the FEs have been interfaced to EPICS, allowing for remote control and constant monitoring of the RGAs, which is useful for diagnosing vacuum problems. Alarm handlers have been implemented in EPICS for all FE systems. Advance warnings (in the form of e-mail to pagers) warn of potential faults, so preventive action can be taken to rectify the problem.

In order to meet the CATs' needs, seven of the ID FEs and one BM FE have been retrofitted with differential pumps for windowless operation of the beamlines. Windowless operation allows the beamline to utilize lower energy x-rays and reduce scattering. Also reduction of flux/brilliance due to x-ray absorption in window assemblies (containing a set of filters) is avoided. All these windowless beamlines have an RGA just downstream of the differential pump. Work on interlocking and alarming on RGA signals is underway.

Problems have occurred in recent months on the FE vacuum systems. The problems were identified to be one of two types. The vacuum fast valve has sprung vacuum leaks in several FEs. The vacuum leak occurs at the wire seal located in the ring surrounding the conflat flange. Similar problems have been reported by other facilities when they baked their valve to 250°C. (At the APS, it was baked only to 150°C.) The seals have been replaced in some of the FEs, which requires venting half the FE and subsequent baking. The other vacuum failure has been attributed to the viton seal in the FE exit valve located just outside the shield wall. This valve was chosen for its characteristic particle-free nature, fast closing speed, and 1-million-cycle lifetime. Failures were observed in the form of slow leaks through the seal. Some of the valves were sent back to the manufacturer for analysis. Based on these results, the manufacturer has modified the valve and has rated the valve only for 100,000 cycles and longer closing times. Thus, all future replacements will be made with series 10 valves, which are 1/3 the cost.

One common failure mode during the past year has been due to the FE cooling water system. This failure triggers the protection system to halt operation of both the beamline and the storage ring. The problem has been traced to the pressure-sensitive transducers. The manufacturer has acknowledged the problem in these devices and has retrofitted them whenever the devices were taken out of the system. In addition it was noticed that most of the components in the FE were not meeting the design specification for coolant flow. All mesh-based components in the FE were subsequently cleaned by a technique developed locally. The cleaning cleared the blockages in the cooling channels and brought flow rates to their design values. The output of the pressure transducers was interfaced to the EPS system. Each flow or differential pressure has both an upper- and lower-limit alarm that can trigger an inhibit for operation of beamline/storage ring. The upper-limit alarm was found unnecessary and was removed. As an added preventive measure, EPICS alarms were set to notify staff when the flow/pressure was within 30% of the trip level. All these enhancements have resulted in increased reliability of this system.

Each FE has two x-ray beam position monitors (XBPMs) installed. These devices can measure the position and angle in both the vertical and horizontal planes in the case of ID beamlines and in the vertical plane in BM beamlines. All the XBPMs in the FEs were instrumented. The current signals originating from the XBPMs were amplified and converted to voltage and fed to a fast ADC processor. The digital output of the ADC processor is transmitted via fiber optic to a VME-based receiver module. The receiver module is located in the storage ring feedback input output controller (IOC) system. High-speed XBPM data are available for the storage ring feedback system for future closed-orbit feedback systems. On 9 of 20 ID front ends, a digital-signal-processor-based XBPM calibrated system has been implemented. Once calibrated, this system reports the x-ray beam position in real units independent of ID gap or storage ring current.

2.6.4 User Beamlines

As the APS moves towards a mature operational state, the Beamline Operations Group has started providing support to the users on a regular basis. Most of the beamlines use processed water for all their component cooling needs. The processed water for each sector is a closed-loop system consisting of a deionized (DI) water plant located in the mechanical mezzanine and a distribution system for each station. Most of the CATs have chosen the DI water plant designed by the APS. Beamline Operations has taken on the responsibility of commissioning and subsequent maintenance of the DI water systems for the CATs. The CATs are provided round-the-clock coverage for emergency repair service on their DI water plants.

The undulator beam delivered at the APS has very high power density and total power. Most of the beamlines use a monochromator as their first optics to handle this powerful beam. Liquid nitrogen is the coolant of choice for the monochromator, as it keeps the optics distortion at a minimum while providing the necessary cooling capacity to handle the high head loads. Most of the beamlines use an Oxford Instruments liquid nitrogen pump for pumping liquid nitrogen through the monochromator crystal. The Beamline Operations Group has taken on the responsibility for providing emergency service and routine maintenance of these user pumps. Spares needed for the service of these pumps are available to meet emergencies.

2.6.5 User Interfaces

At the Advanced Photon Source, all controls are standardized with EPICS. This system consists of equipment interfaced to VME-based hardware. The VME crate (normally called the IOC) talks to the computers via the Ethernet. With EPICS, access to the controls is available from any computer located on the same network. This scheme has a great degree of flexibility.

Most of the CATs have chosen EPICS as the control system for their beamlines. Beamlines routinely need various information from the APS control system. A multi-prong approach was taken to disseminate the relevant information to the user at the APS. The Web has been used as one platform for providing information about the machine. This information is not in real time. The Web platform is used mostly for archived data and for informative purposes. A cable TV system with 14-channel capability was installed around the storage ring, and the information is also distributed to the rest of Argonne including the Guest House. At the current time, only 2 of the 14 channels are being used. The data are in real time providing information about the storage ring operating status on one channel and the beam pinhole image and size on another channel. A plan is underway to provide other desired information on the rest of the channels in the future.

Users requiring data in real time cannot use either of the above-mentioned schemes owing to the need for security and isolation of the control system. An EPICS interface gateway has been developed to overcome this limitation. A high-speed Unix-based Ultra Sparc system was set up with bridges to the two networks. The gateway provides any data that are available in the control system to the users as read-only on a real-time basis. In addition the gateway is used in specific cases to provide specific users access to control equipment in the control system, for example, the IDs. For each of the ID beamlines, users can control their ID from designated computers.

The EPICS gateway has some limitations. Due to the large number of beamlines and users, the performance of the gateway can degrade and will not be able to provide data at the same rate as available on the control system. Hence, for the present, the gateway is throttled down to avoid any down time, while new solutions are sought to mitigate this limitation.

A new system is being implemented using a fiber optic link. Each beamline has a dedicated multiconductor fiber optic cable installed from their respective ID control system IOC (VME-based). The intent of this system is to provide a direct link from the APS control system to the beamline control system while making sure that security is not compromised. The receiver module is located in the beamline control system IOCs. The data flow is unidirectional from the APS control system to the beamlines.

All CATs were provided with a stand-alone receiver module. This module has displays in the form of LEDs and an alpha-numeric display for current. In addition, it has outputs in the form of voltage, current loop, and frequency, corresponding to the stored beam current. All LED displays have a corresponding transitor-transitor logic (TTL) signal for various bilevel signals like injection status, shutter status, orbit correction status, etc. In addition, the revolution clock signal (P_0) is available on these units for users performing timing experiments.

A VME-based receiver module has been successfully tested in one of the sectors. The VME receiver module can be located at any of the beamline station IOCs. The fiber optic link is used by this receiver to provide the data to the user’s experiment. The data from the APS control system are available to the users seamlessly. Installation of the module is under way for the remaining sectors. The VME-based receiver module has sector-specific information available to the users directly in their IOCs. Some of these signals are related to ID parameters, FE beam position monitor (BPM) signals and storage ring particle BPM signals for both the ID and BM beamlines, as well as FE shutter status. In addition, all the common signals, like storage ring current, injection status, etc., are also available.

The fiber optic information system helps relieve the load on the EPICS gateway. In addition, the users have the advantage of having the data available directly in their IOCs for seamless integration to their experimental setup. This system preserves the high level of security to the APS control system and also distributes the load uniformly around the ring to various IOCs. Plans are under way to provide the users with bunch clock signals for timing experiments.

2.6.6 Sector 5 Front-End Problem

At the APS, our first major failure of a FE took place in March 1998, disabling the sector 5-ID beamline from operating for a period of about three weeks. During the maintenance period following the operating cycle, the FE was fixed and the beamline was put on-line. The CAT lost about three weeks of useful user beamline operation time.

In early March, whenever the CAT closed the device to small gaps there was a noticeable rise in the pressure in the FE vacuum system. As time passed, the vacuum further degraded, and the EPS disallowed the opening of beamline shutters. During the next available access to the storage ring, vacuum leak checking identified the problem as the ratchet-wall collimator. The ratchet-wall collimator tube was found to be bent. At the next scheduled maintenance time, the FE was surveyed, and all components downstream of the slow valve were removed. The second photon shutter and the safety shutter were found to be in good condition. The ratchet-wall-collimator vacuum chamber was bent, and a small crater was found about 3 inches from the upstream side of the collimator tube.

After extensive investigation and review, it was determined that the wall collimator tube should not be constrained at both ends because the constraint prevented the wall collimator tube from expanding and contacting linearly. If both ends are constrained, the tube can bend at the least constrained point. Once the tube started bending, it was close to the beam and in a posistion to be exposed to heating from the beam, which in turn resulted in further bending. Eventually the bottom surface of the collimator tube was in the path of the direct undulator beam, which caused a crater and the subsequent vacuum failure.

At the current time, the cause of the contraction of the collimator tube is not clear. However it was clear that unconstraining the collimator tube would have averted the failure. As a preventive action, all ratchet-wall collimators were modified to allow for dimensional changes in the tube.

2.7 Interlock Systems and Instrumentation

The Interlock Systems and Instrumentation (ISI) Group is responsible for generating and/or supporting the design, installation, testing, and maintenance of the PSS, EPS, and FE instrumentation. This includes any and all documentation, testing, and field-work required for supplying the XFD with high reliability systems. Each system consists of numerous subsystems that are high reliability and fail safe. The PSS is a redundant interlocked system that monitors personnel access into beamline enclosures. The EPS is an interlocked system that reduces risk of damage to FE beam transport equipment. The group is organized into three functional blocks. The interlock system design section provides interlock systems requirements, scheduling, budget/cost development and control, drafting, and project management support. These systems are designed to applicable codes, orders, and standards for such systems. Software is developed in the software development section under the software development plan and conforms to the Laboratory's Software Quality Assurance Plan. The hardware function in the hardware design section relates to the design, systems requirements, scheduling, budget/cost, drafting, and project management support of FE instrumentation.

2.7.1 The APS Personnel Safety System

Introduction

The APS is designed with the capability to operate at least 70 beamlines concurrently. Each beamline includes several shielded experiment stations. Personnel access into these stations is controlled during beamline operation via the APS/XFD PSS. The PSS is an engineered safety system that interlocks personnel access to these stations with x-ray beam-off conditions via beam shutter operation and, if required, storage ring operation.

Although there are a variety of beamline designs that reflect the types of experiments being done at the APS, basic PSS configuration and control functions remain the same. If required, specialized user control panels are incorporated into the standard library of PSS hardware.

The PSS is designed to comply with accelerator safety standards in DOE Orders and other relevant good practices for accelerator facilities. Among the requirements derived from the above criteria, to which the PSS conforms, some of the more important items are as follows:

- The system is designed to be fail safe, so that common failure modes leave the PSS in a safe, beam-off state.

- The designs incorporate redundant protection, ensuring that no single component or subsystem failure leaves the PSS in an unsafe condition.

- Provisions for testing are included, so the proper component and system function may be verified.

- Access and egress controls are incorporated so that personnel are not exposed to x-ray radiation. These include emergency shut-off devices, status signs, search and secure procedures, and emergency exit mechanisms.

- A strict configuration control system protects documentation, circuits and software against unauthorized and inadvertent modification. Critical devices are clearly labeled to note that tampering is strictly forbidden.

PSS Configuration Management Plan

Safety experts consider rigorous configuration management (CM) mandatory for any organization responsible for developing safety critical systems. Thus, CM is essential to the mission of the ISI Group. XFD has implemented CM that provides the mechanism whereby assurances can be made that the appropriate system is being used.

PSS Installation Status

Although the number of new installations has not increased dramatically over the last 16 months, the biannual requirement for revalidation of the PSS systems required a continued level of support. The number of user stations instrumented with the PSS is shown in Figure 2.6. The figure also shows the number of validations performed during this period and summarizes the planned future activities.

Support for PSS Validations

Scheduled periodic validations of each beamline PSS afford APS users the opportunity to request operational changes in these systems. Thus, over 95% of the non-trivial PSS validations conducted during a year involved either system or user changes, which require both development and configuration management support within the ISI Group. Typical technical support needed for each system change in a given beamline PSS includes engineering support for developing, reviewing, testing and documenting proposed design changes. Additionally, technician support is needed for installation and testing.

PSS Improvements in Support of Operations

Improvements in the current PSS design are planned in the areas of operational reliability and testing efficiency. The present PSS design incorporates permissive protective logic and some command/control functionality. The new PSS design will not have command/control features in its safety-critical portion, as does the current PSS design. Thus, the new PSS design will conform to all relevant mandated DOE and

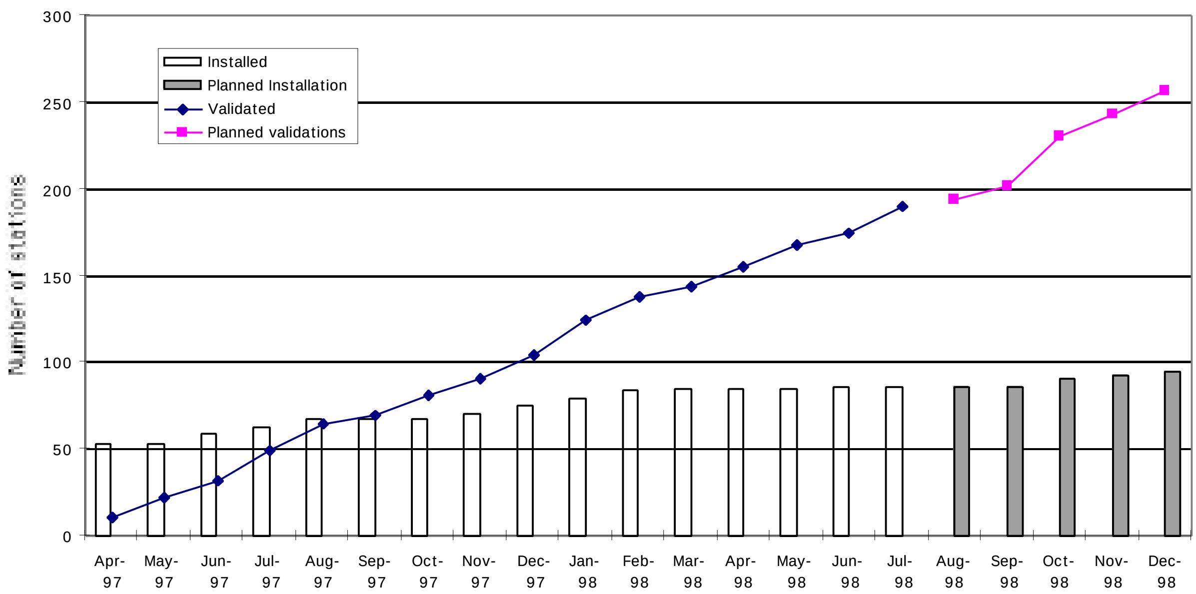

Fig. 2.6 Number of PSS installations and revalidations (completed and planned).

ANL safety design criteria and will provide better operational performance, with virtually exhaustive safety test coverage while reducing the testing duration. Ultimately this means a more seamless PSS interface for the APS users while providing more enhanced personnel access safety.

PSS EPICS Interface

Based on run time experience, it is evident that the PSS must have significant diagnostics available to minimize user beamline downtime.

Furthermore, quick accurate trouble analysis, useful data logging of PSS parameters, and user “remote” operation/monitoring of some PSS parameters not only enhance beamline operating efficiencies but provide essential information for preventative maintenance. These fundamental diagnostic and logging tools are best provided via an EPICS interface with the PSS.

The needed diagnostics and logging capabilities will be provided by configuring the PSS EPICS so there is one PSS EPICS IOC per beamline.

2.7.2 The Equipment Protection System

Introduction

The APS has presented a number of design challenges in protecting FE and beamline components from being damaged by thermal loads produced by high-brilliance hard x-rays. Another major goal is to ensure that the storage ring vacuum is not compromised under any vacuum-failure scenario in the FE or beamline.

The FE Equipment Protection System (FEEPS) monitors and controls devices located in the beamline FEs. Actions taken depend largely on the severity of the fault, ranging from merely setting an alarm, to closing shutters and valves, to inhibiting stored beam. One of the major considerations driving system design was to limit beam aborts thus contributing to higher operating efficiency of the facility.

Fail-safe principles are incorporated into the design, and the system will lapse into a predetermined safe condition (de-energized to trip) following a failure, including loss of power, air-pressure drop, drop in water flow, shorted outputs, and open circuits.

System Overview

Programmable logic controllers (PLCs) are used to handle all system monitoring, control, troubleshooting, and reporting functions. PLCs allow for the design of a very advanced interlock and control system that can handle a large number of distributed I/O points. Each FE is provided with an autonomous equipment protection system that monitors the following parameters: cooling water flow and differential pressure, vacuum sensors, pneumatic pressure, photon and safety shutter positions, positions of vacuum valves, and status of the systems to which the FEEPS interfaces

In order to isolate different power systems, all interfaces between the FEEPS and other systems and subsystems are implemented through relay contacts. These interfaces are listed in Table 2.3.

Installation Status

Overview

Currently 41 FEEPS are instrumented, commissioned, and in operation. This includes 40 systems planned for the Phase-1 installation period, as well as the 35-ID FEEPS. Phase-1 installation data (in percent) is reflected in Fig. 2.7.

Additional systems are being brought on line on a regular basis. A FEEPS system for the 35-BM FE will be instrumented and validated in the fourth quarter of 1998.

All 41 systems have been commissioned at least up to the first photon shutter (PS1). However, full implementation of the FEEPS is governed by the beamline installation pace. It is the responsibility of the XFD personnel to maintain a high level of reliability and availability of the FEEPS. To accomplish this, in addition to the initial system validation of proper operation, a full functional revalidation of each FEEPS system is being conducted at twelve-month intervals.

Table 2.3 System Interfaces and Functions

System	Signal Functions
Beamline PSS	Monitor shutter-open positions Control of photon shutters
Insertion Device	Monitor gap for ‘max open’ status Control emergency gap open
SR ACIS	Monitor shutter-closed positions
Vacuum System	Monitor SV, FV, CC1 and CC2 status Control SV and FEV Permit vacuum controller operation in local mode
Beamline EPS	Monitor interlock summation signal and request to close FEV Send FE shutter and FEV status
SR MPS	Control permission to run storage ring RF
EPICS	Monitor status of the system Control FE shutters and vacuum valves Allow remote reset of the trips

Reporting and Control

Status information of all FEEPS systems is incorporated into the EPICS-based APS control system. This allows monitoring of the interlock system from any networked PC, X terminal or Unix workstation. In addition, all system trips are captured to facilitate troubleshooting and performance analysis.

Graphical displays include an overall view of the storage ring and FEs, as well as zoom-in screens for each interlock and control system. The information available is comprehensive, ranging from the upper level summation tables down to the individual field device sensors.

The graphical user interfaces also make it possible to control FE shutters and vacuum valves, as well as reset latched trips remotely. This control capability is under configuration control and is only available to authorized personnel.

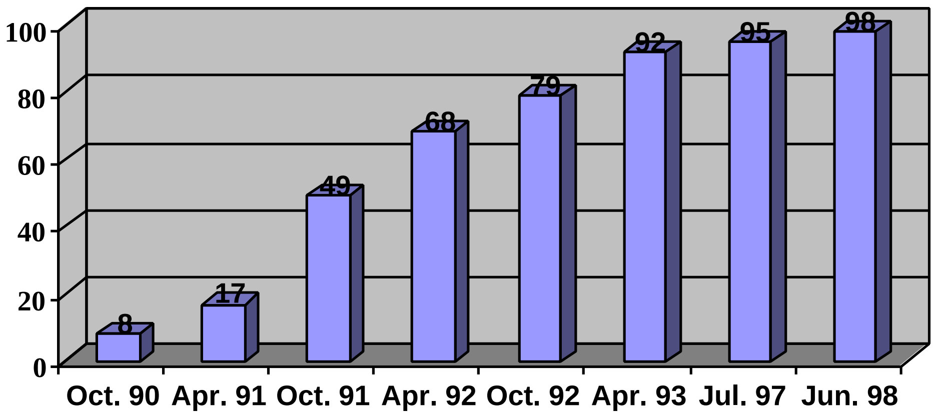

Fig. 2.7 Phase-1 FE Equipment Protection System installation progress (in percent).

New Initiatives

A number of important system upgrades are planned. Some are listed below.

- Place PLC processors on DH+ bus. This will allow PLC access for program download and troubleshooting from a "single" location.
- The fast valve (FV) is triggered to close by a dedicated cold cathode gauge. The FV trigger to close causes an immediate beam abort. Equip ID FEs with a redundant vacuum gauge, so that both sensors will have to indicate pressure rise for the FV to close.
- On bending magnet FEs, don't dump stored beam on FV trigger - PS1 will close to protect the valve.
- Enhance EPICS displays by adding system schematics for real-time display and control.

Operations Experience

The operation of the FEEPS began in December 1994. The last three and a half years have provided valuable operating experience. Some process variables and time delays were fine-tuned. Most noticeably, we have decided to do away with temperature interlocks and to rely only on the doubly redundant cooling water interlocks. The main reasons for not interlocking on temperature are the low level of reliability, as has been observed at other light source facilities, and the potential for nuisance trips.

During the more than 3.5 years of operation, not a single storage ring beam dump was caused by the FEEPS. The trips were all for "legitimate" reasons, most due to the flow rate dropping out of the predetermined range, and some resulting from the vacuum system faults. In all cases, the FEEPS responded the way they should, and there have been no unexplained trips.

2.7.3 Instrumentation

Instrumentation Improvement in Support of Operations

A wireless communication network for efficient operations support is planned. The intent is to provide a portable computer with a wireless communication interface that can be used to assist in diagnosing PSS or FEEPS problems. This unit will supply system information, automated trouble-shooting guidance and voice communications that can be carried to the system hardware in question on the experiment hall floor.

Engineering support is being provided for the following beamline instrumentation projects:

- High voltage solenoid pulser – the APS has need of a high-speed x-ray beam chopper to be used within a program devoted to time-resolved measurements. The required high-speed chopper will operate within a time window of 2.35 µs. Also, the beam chopper motor must have the speed, precision and stability necessary to phase lock the time window of the beam chopper to the revolution frequency of the storage ring and the variability to allow matching the beam chopper time window opening to the “bucket” pattern of the APS synchrotron radiation. An 80K rpm motor from Speedring and associated feedback control is planned to implement this design goal.
- Engineering analysis of FE shutter operation using high-speed data acquisition systems interfaced to the FE EPICS control system.

2.7.4 Controls

Due to the flexibility provided by EPICS, all data are available at all times to anyone with access to the computer network. At the APS, we have a separate subnet with restricted access for all the control systems. All the IOCs are located on this subnet. This provides an added security from unwarranted access to the IOCs. With the location of a EPICS gateway, data from the control system are provided to other subnets.

In a typical FE, currently EPICS can only read and is not allowed to control. All controls for the FE have to be performed at a location on top of the storage ring. All vacuum pump and gauge controllers are interfaced with EPICS. The interface enables the ion pump current and the vacuum to be read continuously. All water flow and pressure systems are also interfaced to EPICS via the RS-485 interface available in the interface controllers. All data from EPICS are constantly logged. This provides for later analysis of specific trends. The constant monitoring of data provides us with flexibility for advance warning on failures, thereby preemptive action can be taken to avoid them.

The XBPM raw voltage signals for the current amplifier are interfaced to the control system via an RS-485 interface. The normalization of the raw signals is performed in the IOC. All signals, both raw and normalized, are available via EPICS.

Insertion device control is also implemented with EPICS. The ID motor controllers are commanded by EPICS, and the encoders are used to read the precise position of the device. Using the EPICS gateway, added security control to the IDs is provided to specific users of a particular beamline.

The PSS and FEEPS operator/user interface (OUI) is provided for APS facility use. The remote OUI for PSS and FEEPS has the capability to interface with EPICS. User screens have been developed that graphically represent the PSS status, and the remote OUI does not control any PSS functionality.

2.8 Experiment Floor Operations

In March 1998, the APS floor coordinators became members of the Experiment Floor Operations Group. Their principal responsibilities remain the same: they provide the day-to-day technical support for the APS users. In addition to their support role, the floor coordinators provide the primary APS oversight of beamline operations. The coordinators' offices are distributed around the experiment hall, with two coordinators assigned to the four sectors that are associated with a specific LOM. Floor coordinators familiarize themselves with the operation of the beamlines within their areas of responsibility and have the authority to suspend operations if they feel that unsafe conditions may exist. Whenever the facility is operating or whenever beamlines are undergoing significant modification, a floor coordinator will be "on duty" representing the APS.

During the past year, five floor coordinators have been hired. The floor coordinator team is being built with personnel who are experienced in a variety of different aspects of the construction and operations of research facilities. In addition to the on-the-job training for new coordinators, a seminar series was organized to introduce the coordinators to some of the experimental programs at the APS as well as to develop a deeper understanding of the detailed operation of the APS technical systems. As the number of users increases, so does the variety of samples and experiments on the beamlines. The floor coordinator duties will expand to provide service in the areas of biological, radioactive, and chemical sample handling.

2.8.1 Shielding Validation of the Experiment Stations

The Experimental Facilities Division, in collaboration with the Health Physics Personnel from ANL's Environment, Safety and Health (ES&H) Division, performs the shielding verification of all the user experiment stations in the presence of CAT personnel. The governing process for commissioning is documented and has been approved by the DOE. The CATs are informed immediately of any shielding deficiencies discovered during the enclosure commissioning. Activity on the beamline cannot proceed until the deficiency is mitigated. The CATs are allowed to proceed with commissioning activity of beamline instruments only after successful completion of shielding verification of the enclosures.

Shielding verification is done for bremsstrahlung, synchrotron radiation, and neutrons. So far, 45 first optics enclosures/ white-beam stations and 33 pink/mono-beam stations have been verified at the APS.

2.8.2 Measurement of Radiation Dose Received by IDs

The radiation dose received by the magnetic structures of the IDs was monitored for each run. Radiochromic films were placed at various locations by each of the IDs before each run. The accumulated dose shows that the maximum dose received by the IDs until now is in the range of a few Mrads (5-10 Mrads).

A program to study the degradation of the permanent magnets as a result of high radiation doses is in progress. Nd-Fe-B permanent magnet samples will be irradiated with x-rays, gamma rays, and neutrons under controlled conditions. The total absorbed dose in each case will be measured by an appropriate high-dose dosimetry technique, such as radiochromic films or photoluminescence dosimeters. The temperature of the magnet during irradiation will be closely monitored. The first batch of magnets will be irradiated by x-rays at the 20-BM beamline during Run 4 of 1998. Gamma irradiation will be measured at the high-dose Co-60 gamma cell (9 KGy/h) at NIST.

2.8.3 Measurement of Bremsstrahlung Absorbed Dose in Tissue Phantom

High-energy electron storage rings generate energetic bremsstrahlung photons through radiative interaction of electrons (or positrons) with the residual gas molecules and other components inside the storage ring. At the APS, where the beamlines are channeled out of the storage ring, a continuous bremsstrahlung spectrum, with a maximum energy of the positron beam is present. Measurement of the primary bremsstrahlung energy spectra has been conducted at the APS ID beamlines and has been reported in the *Experimental Facilities Division Progress Report 1996-97* (ANL/APS/TB-30).

A polymethyl methacccrylate (PMMA) slab phantom of 30 cm × 30 cm × 30 cm is used to measure the absorbed dose by bremsstrahlung radiation in tissue equivalent material. Thermoluminescent dosimeters (TLDs) (LiF, TLD-700) are used to measure the dose. The PMMA slabs were placed in the bremsstrahlung beam in the FOE of the 15-ID beamline. The TLDs measured the absorbed dose in the longitudinal and the transverse directions in the phantom. The preliminary results indicate a maximum normalized absorbed dose rate of 1.0×10^{-2} mGy/h/nT/mA. Detailed analysis of this experiment is underway.

2.8.4 Photoneutron Dose Measurements in the First Optics Enclosures

Bremsstrahlung of sufficiently high energy (>10 MeV) can interact with beamline components, such as beam stops and collimators, generating neutrons of varying energies. There are three main processes by which neutrons may be produced by the high-energy bremsstrahlung photons: giant resonance dipole decay ($10 < E_\gamma < 30$ MeV), quasi-deuteron production and decay ($50 < E_\gamma < 300$ MeV), and a photopion produced cascade ($E_\gamma > 140$ MeV). At the APS, where bremsstrahlung energy can be as high as 7 GeV, production of neutrons invarying yields is possible from all three processes.

A simultaneous measurement of bremsstrahlung and the corresponding photoneutron dose rates from different targets like Fe, Cu, W, and Pb was conducted at the FOE of the APS beamlines to obtain the photoneutron dose rates as a function of bremsstrahlung power. An Andersson-Braun remmeter that houses a sensitive ^{3}He detector is used for neutron dose measurements. The dose equivalent rates, normalized to bremsstrahlung power, are measured with the four targets. The results are given in Fig. 2.8.

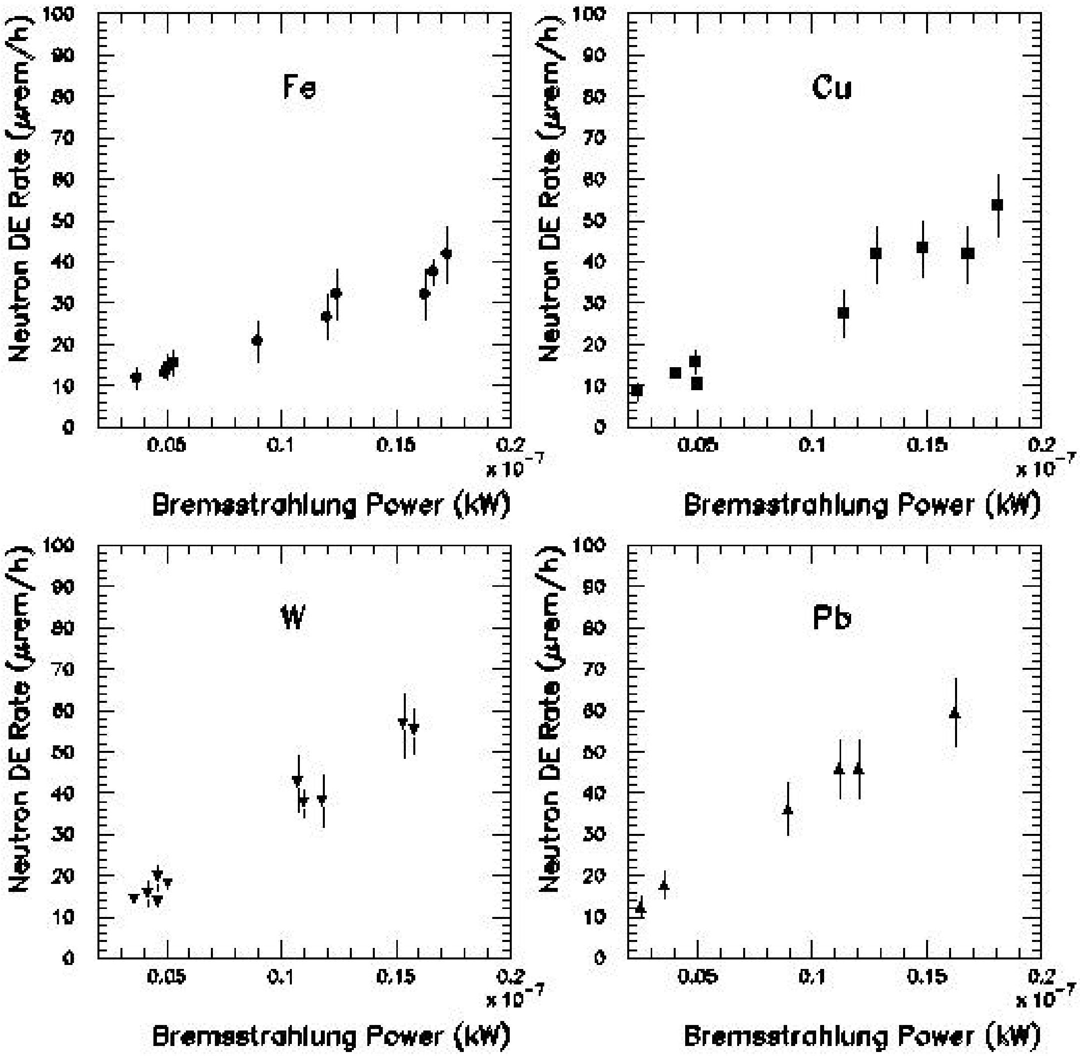

Fig. 2.8 The photoneutron dose equivalent rate, measured 80 cm lateral from each target center, as a function of the incident bremsstrahlung power.